Findings from the first detailed fauna survey of Quanda Nature Reserve, New South Wales

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ABSTRACT

Quanda Nature Reserve was originally established in 1963 to conserve the remnant old growth mallee vegetation and its suspected Malleefowl, *Leipoa ocellata*, population. This study reports on the first detailed fauna survey of the reserve since its establishment. Eleven survey techniques were used in order to identify as many vertebrate species as possible; with all techniques, except call playback, detecting at least one species. Nine of the techniques detected species not detected by any other technique (i.e. "unique species"). The effectiveness of each technique for detecting species varied depending on the fauna group. A total of 110 native vertebrate species and 10 exotic vertebrates were identified, of which 39 native and seven exotic species had not previously been recorded within the reserve. Seven of the native species are listed as threatened, and five of the exotic species are listed as key threatening processes, under NSW State legislation. No evidence of recent *L. ocellata* activity was observed. This survey substantially increased the knowledge of the fauna diversity within the reserve, particularly within the old-growth mallee habitat. Having a comprehensive understanding of species diversity and habitat associations within the reserve will be critical in underpinning conservation management plans and actions for the reserve which effectively achieve biodiversity conservation goals.

Key words: Biodiversity, Survey technique, Arid zone, Trap effectiveness, Trap success, Malleefowl.

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Introduction

The New South Wales (NSW) protected areas network covers a total land area of more than 6.9 million hectares (approximately 8.66 % of the total State land area) and is comprised of 845 protected areas of varying governance (Department of Sustainability, Environment, Water, Population and Communities 2011). These protected areas are categorized into 10 main "types" according to their biodiversity and/or natural asset value, the level of legislative protection afforded to them, and the degree of human use permitted. Of these 10 types, areas classified as "nature reserve" are among the most highly protected from human disturbances, with access being limited and carefully managed. Nature reserves are defined as areas that are "…in a predominantly untouched, natural condition which have high conservation value…" and are characterized by "…outstanding, unique or representative ecosystems, native plant and animal species or natural phenomena" (Office of Environment and Heritage 2011). Accordingly, management priorities for nature reserves centre on the protection and conservation of the natural value/s, and scientific research aimed at understanding and better managing these values is often an important objective (Office of Environment and Heritage 2011).

The original Quanda Nature Reserve (hereafter referred to as Quanda NR or "the reserve") was formally gazetted as a nature reserve in 1963 in a bid to conserve an area of remnant, old growth mallee vegetation and its suspected Malleefowl, *Leipoa ocellata*, population. An adjacent lot was added to the original gazettal in 1966, bringing the total area of the reserve to approximately 854 ha. In 2003, the National Reserve System program funded the additional purchase and gazettal of the adjacent "Millyvale" property, which extended the reserve to its current area of 4,784ha (Office of Environment and Heritage 2011). The reserve falls under the jurisdiction of the NSW National Parks and Wildlife Service (NPWS) (Cobar Area, Western Rivers Region) and as such, is managed in accordance with the *National Parks and Wildlife Act 1974* (New South Wales Government 2011a).

Although established specifically to protect *L. ocellata* habitat, there has been no specific survey aimed at determining the presence or absence of the species within the reserve, despite its long history as a nature reserve. Without baseline data, no species-specific or targeted habitat management has been implemented. Existing management of the reserve has been limited to standard actions (e.g. aerial baiting for pest species) with the lack of information regarding fauna species' occurrences within the reserve preventing more specific and targeted actions. This lack of information has largely been due to limited resources and funding available to conduct detailed fauna surveys and monitoring programs. Only one previous survey specifically targeting Quanda NR has been conducted, with this survey focusing on the reserve's flora, not its fauna (e.g. Porteners 1998, 2003). Any fauna records for the reserve or the surrounding area, are generally derived from larger, more regional scale surveys, which included Quanda NR as a small component (rather than the sole focus) of the much broader study area (e.g. Masters and Foster 2000; NSW National Parks and Wildlife Service 2001). Such broader scale studies often rely on rapid survey assessment techniques and/or incidental observations and most of the existing fauna records from such surveys are more than a decade old; only four records are from within the last decade, and only two from within the last five years. As a result, there is limited existing information regarding the reserve's fauna community, which clearly has implications for the reserve's conservation management. A targeted, detailed fauna survey was considered an essential step for underpinning the reserve's Plan of Management (PoM), which was in the preliminary draft stages at the time of this survey.

The primary objective of this project was to provide a baseline species occurrence list which would underpin the development of the reserve's PoM and its short- and long-term conservation management actions and priorities. The baseline species list was to be derived from a detailed vertebrate fauna survey of Quanda NR, with a focus on the mapped old growth mallee vegetation, as requested by the managing NPWS Area. The results of the detailed fauna survey are presented here, in addition to comments on the effectiveness of different trapping and survey techniques employed. Supplementary information relating to this survey is available in Garden *et al.* (2009).

Methods

Background Review

Information regarding known and likely species occurrences within the reserve and it's surrounding locale (within 10km) was collated from a review of previous works (survey/investigations) and species records, including: discussions with relevant personnel; reviews of the published and grey literature; a review of relevant legislation, including the NSW *Threatened Species Conservation Act 1995* (TSC Act) and the federal *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act); and reviews of relevant online databases, including those associated with relevant legislations (e.g. the Protected Matters database), and the NSW Wildlife Atlas (Department of Environment, Climate Change and Water (now Office of Environment and Heritage) 2008).

Study area

Quanda NR (31°46' S, 146°42'E) comprises 4,784 ha of land within the Bogan Shire Council of central NSW. Located approximately 90 km south-east of Cobar (Figure 1), the reserve exists within a matrix of privately owned agricultural paddocks containing some scattered trees, and has been effectively isolated since broad-scale clearing in 2000 which removed vegetation corridors that previously linked it to vegetation in the north (Metcalfe *et al.* 2003). Within the broader landscape context, Quanda NR is one of a small number of protected areas, all of which are highly isolated by the agricultural matrix. The closest substantially vegetated, non-agricultural, areas to Quanda NR are State Forests located approximately 20-25 km to the north and south (Figure 1); the closest formal protected area is Tollingo Nature Reserve, located approximately 100 km to the south.

Quanda NR is bounded to the north and south by unsealed public access roads and to the south, east and west by privately owned grazing/cropping paddocks (Figure 2). Within the adjacent western paddocks, a stand of mallee vegetation (mostly regrowth) grows adjacent to the reserve. Potential water sources within the reserve are limited to a small stretch (~ 250 m) of Yarran Creek which passes through the reserve's south-western corner, and several minor natural and man-made drainage lines and dams (tanks) (Figure 2). In addition, the natural gilgai formations in the eastern Millyvale extension may serve as ephemeral water sources following heavy rains. At the time of the detailed fauna survey, the only apparent standing water was in three of the dams: D2, D4, and D6 (Figure 2).

Land-use and disturbance history

Historical European land-uses of Quanda NR were primarily agricultural, including grazing and cropping in the south and south-east portions of the reserve. At the time of the survey, formal fire trails ran along much of the reserve's boundaries and also bisected the reserve in a northeast-southwest direction at two locations, with the northern of these being a wide (~8 m) primary access track, and the southern one being a narrow (~3 m) secondary track which was largely overgrown (Figure 2). Four minor access tracks also meandered through the reserve, providing access to seven man-made dams, vestiges of the reserve's farming history (Figure 2). Although not open to the general public, several informal and illegal vehicle trails, as well as temporary livestock holding pens, identified the use of the reserve by kangaroo poachers and goat/pig hunters.

In addition to illegal hunting practices, known disturbances to the reserve include invasions by exotic pests (e.g. pigs, goats, foxes), and a single wild fire event in March, 2003. The wild fire was primarily contained to mallee vegetation adjacent to the reserve's western boundary, though it spread into approximately nine hectares of remnant mallee vegetation within the reserve, midway along the western boundary (National Parks and Wildlife Service 2012). With the exception of this single recorded event, at the time of this survey, the majority of the mallee habitat within Quanda NR was considered to have been unburnt for over 50 years (National Parks and Wildlife Service 2012).

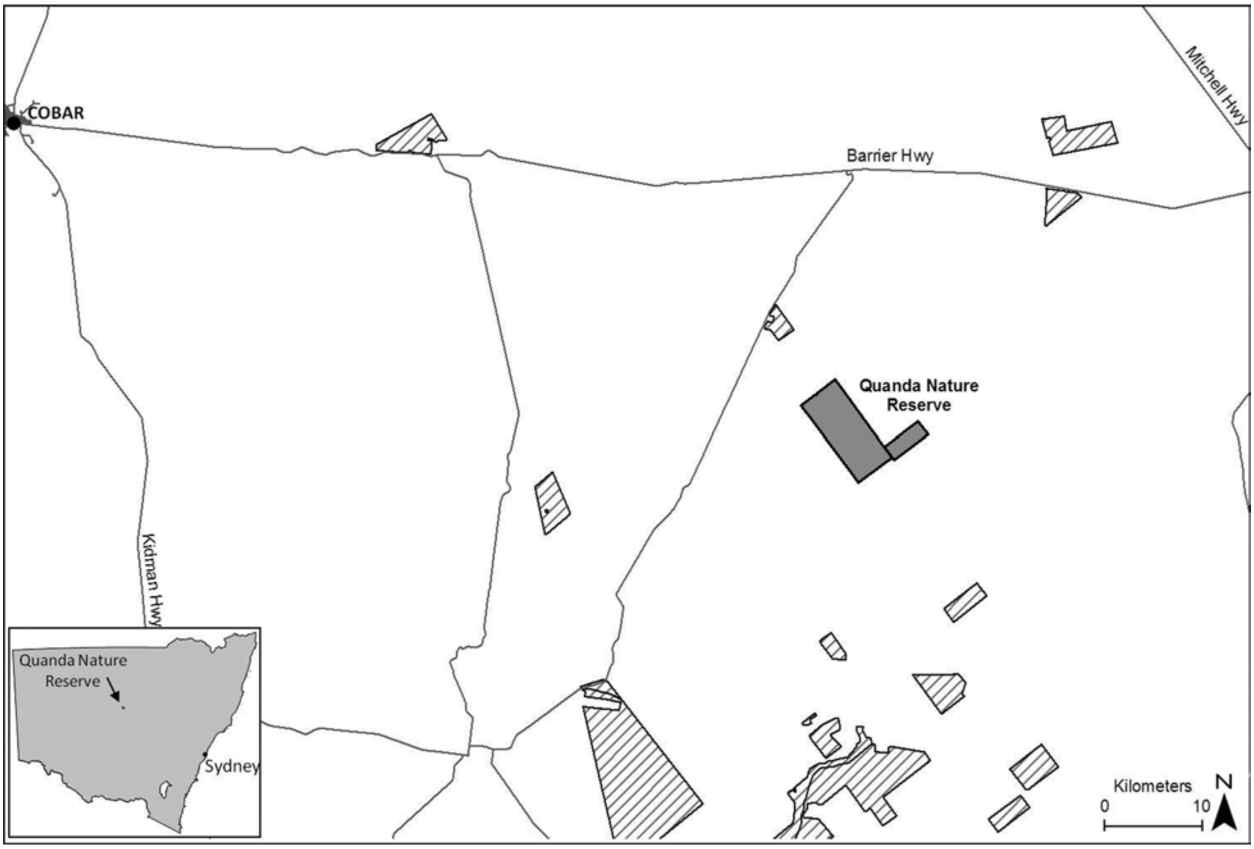
COBAR
Barrier Hwy
Mitchell Hwy
Kidman Hwy
Quanda Nature Reserve
Quanda Nature Reserve
Sydney
Kilometers
0
10
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Figure 1. Contextual location of Quanda Nature Reserve within New South Wales. Inset map shows Quanda Nature Reserve location with the State. Main map shows Quanda Nature Reserve (■) relative to the main town (Cobar), roads and highways, and State Forests within the vicinity (▨).

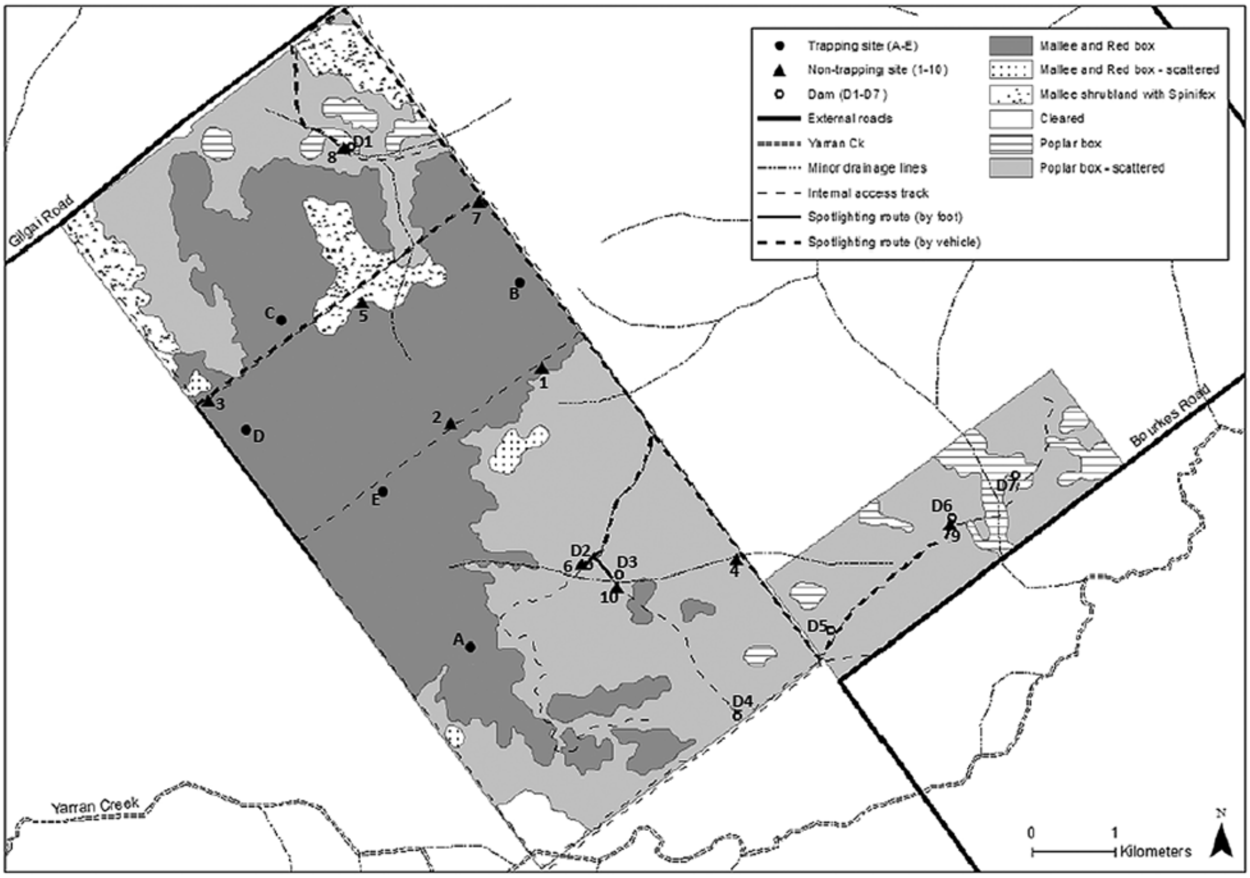
Trapping site (A-E)
Non-trapping site (1-10)
Dam (D1-D7)
External roads
Yarran Ck
Minor drainage lines
Internal access track
Spotlighting route (by foot)
Spotlighting route (by vehicle)
Mallee and Red box
Mallee and Red box - scattered
Mallee shrubland with Spinifex
Cleared
Poplar box
Poplar box - scattered
Gilgai Road
Bourkes Road
Yarran Creek
A
B
C
D
E
1
2
3
4
5
6
7
8
9
10
D1
D2
D3
D4
D5
D6
D7
0
1
Kilometers
N

Figure 2. Vegetation communities, internal infrastructure, waterways, dams, spotlighting routes, trapping sites, and non-trapping sites, within Quanda Nature Reserve. Survey techniques used at each dam/site/route are shown in Table 1.

Vegetation/habitat mapping and trapping site selection

The existing vegetation mapping for the reserve (Porteners 2003) (Figure 2) was used to guide the selection of survey sites. Five "trapping" sites were selected within the old growth mallee habitat (i.e. "Mallee and Red Box") based on the existing mapping, in conjunction with desktop GIS (ArcMap, version 9.2), aerial photo interpretation, and subsequent ground-truthing, (Figure 2). Trapping sites were located a minimum of 1 km apart in an effort to maintain spatial independence. Ground-truthing of trapping site suitability (e.g. correct habitat type) and feasibility (e.g. access) occurred during two reconnaissance trips to the reserve. These five trapping sites formed the basis for the standardised survey design (Figure 3). Non-trapping survey techniques were used predominantly along reserve tracks, and at an additional 10 "non-trapping" sites located in various vegetation communities (Figure 2). The use of survey techniques at these additional tracks and sites were not standardised.

Fauna survey

Duration and conditions

The detailed fauna survey was conducted over four consecutive nights in October 2008. Within the month prior to the detailed fauna survey, two reconnaissance visits to the reserve were undertaken to ground-truth and establish survey sites, and two preparation days were additionally spent on the reserve immediately prior to the start of the detailed fauna survey period. Weather conditions during the detailed fauna survey period were fine and hot, with daily temperatures ranging from 18-37 ºC, and average daily wind speeds of approximately 35-54 km/hr (Bureau of Meteorology 2009). No rainfall was recorded during the detailed survey period, though approximately 12 mm was recorded 32 days prior (Bureau of Meteorology 2009).

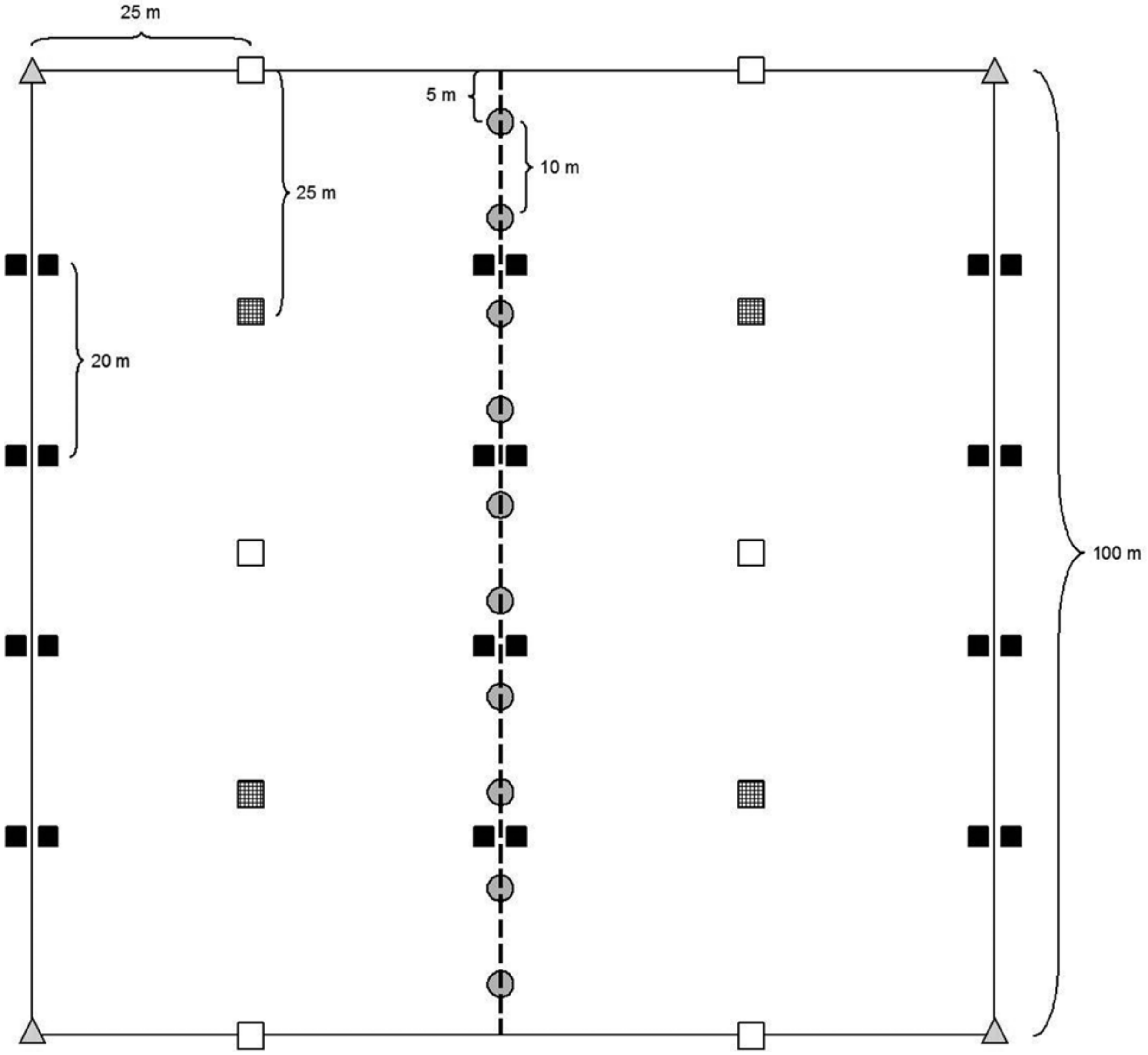

Figure 3. Design of standardised, "trapping" sites showing trap arrangement along three parallel transects: Pit-fall traps (○) with drift fence (- - -), Elliot traps (■), Cage traps (▦), Hair funnels (▲), and Sand plots (□). Solid line represents site boundary.

Survey techniques

Eleven trapping and non-trapping survey techniques were used in various combinations at the different survey sites and along survey tracks (Table 1). Trapping techniques used were: cage traps (~720 x 420 x 370 mm), Elliott traps (size A, 300 x 100 x 80 mm), and dry pit-fall traps (with 30 cm high drift fences). Non-trapping techniques were: hair funnels (FaunaTech design), timed bird census (2 ha, 20 mins), AnaBat^{TM} recording, call playback, spotlighting, track/trace identification (e.g. scats, burrows, scratches, feeding signs), and active searching. Incidental species observations were recorded during all time spent within the reserve.

Trapping site techniques and design

The five trapping sites (A-E, Figure 2) were surveyed using eight techniques (Table 1). The techniques used at trapping sites were employed in a standardised manner. Incidental and active search records were also collected opportunistically. Each trapping site was comprised of five parallel transects (100 m long; 25 m apart), along which a total of 24 Elliott traps, four cage traps, four hair funnels, 10 pitfall traps (with 30 cm high drift fence), and six sand plots (1 m^2) were established (Figure 3). Without deviating more than 1 m from transects, cage traps, paired Elliott traps, and hair funnels were positioned so as to maximise the possibility of being encountered by an animal (Sutherland 1996; Cunningham *et al.* 2005). Pit-fall traps were positioned at 10 m intervals along the centre transect with a continuous drift fence running between them (Figure 3). In addition, each trapping site was also surveyed for birds on three consecutive mornings and afternoons using the bird census technique and the 2 ha search area being centered on each site's central pit-fall trap.

Cage traps, Elliott traps and hair funnels were baited with the standard Australian small mammal bait mixture of peanut butter, rolled oats, and honey (Menkhorst and Knight 2001), with vanilla essence also added. A piece of apple was also used as bait in the cage and Elliott traps, and cage traps were additionally baited with a chicken neck. Pit-fall traps and sand plots were left unbaited. Cage and Elliott traps were set each afternoon before sunset and checked for captures within three hours of sunrise the following morning. Elliott traps were closed during the day, whereas cage traps remained open, unless temperatures rose above 35 °C, at which point they were also closed.

Dry pit-fall traps were established at least one week before the survey period to minimise localised digging-in effects. Pit-fall traps were checked each morning and afternoon and remained open for the entire survey period. Sand-plots were checked for identifiable tracks each morning and afternoon before being swept clean. Hair funnels

	Site reference	Survey technique										
		CT	ET	PF	HF	T/T	An.	BC	CP	Sp.	AS	IO
Trapping sites	A	✓	✓	✓	✓	✓		✓			✓	✓
	B	✓	✓	✓	✓	✓		✓			✓	✓
	C	✓	✓	✓	✓	✓		✓			✓	✓
	D	✓	✓	✓	✓	✓		✓			✓	✓
	E	✓	✓	✓	✓	✓		✓			✓	✓
Non-trapping sites	1					✓		✓				✓
	2					✓		✓				✓
	3					✓		✓	✓		✓	✓
	4					✓		✓				✓
	5					✓		✓				✓
	6					✓	✓					✓
	7					✓	✓					✓
	8					✓	✓		✓			✓
	9					✓			✓		✓	✓
	10					✓					✓	✓
	Spotlighting routes					✓				✓	✓	✓
	Dams (1-4 & 6)					✓				✓	✓	✓
Total survey effort		80 TN	480 TN	200 TN	80 TN	Opp.	17hrs	6hrs 40min	3hrs 45min	16hrs	Opp.	Opp.

Table 1. Survey techniques employed at trapping and non-trapping sites/routes (CT = cage trap, ET = Elliott trap, PF = pit-fall trap, HF = hair funnel; T/T = track or trace, An. = AnaBat^{TM}, BC = timed bird census, CP = call playback, Sp. = spotlighting (foot and car combined), AS = active search, IO = incidental observation). The total survey effort for each technique is also shown (TN = trap nights, hrs = hours, min = minutes, Opp. = opportunistic), and site references refer to those shown in Figure 2.

were set at the start of the survey period week and left undisturbed for a total of two weeks. Hair samples were identified by an independent expert (Barbara Triggs).

Non-trapping survey sites and tracks

Seven non-trapping techniques were used at the 10 non-trapping sites, at dams, and/or along the survey tracks, though not all techniques were standardized by time or location (Figure 2, Table 1). Active searches, track/trace identification, and incidental observations (including call recognition) occurred opportunistically throughout the survey period. Timed bird censuses occurred as soon as possible after sunrise; birds identified during the census period but outside of the 2 ha search area were listed as incidental records. The AnaBat^{TM} bioacoustics bat monitoring system was used to record micro-bat echolocation calls at three locations; at Site 6 (Figure 2) recordings were taken over two partial nights, whereas a full night (approximately 8 hrs) of recording occurred at Sites 7 and 8. All recordings were analysed by an independent expert (Greg Ford).

Call playback was used to survey for nocturnal mammals and birds that may have occurred within the area (based on existing available database records): Sugar Glider (*Petaurus breviceps*), Koala (*Phascolarctos cinereus*), Tawny Frogmouth (*Podargus strigoides*), Spotted Nightjar (*Eurostopodus argus*), Australian Owlet-nightjar (*Aegotheles cristatus*), Bush Stone-curlew (*Burhinus grallarius*), Barking Owl (*Ninox connivens*), Masked Owl (*Tyto navaehollandiae*), Eastern Barn Owl (*Tyto javanica*), and Southern Boobook Owl (*Ninox novaeseelandia*). Pre-recorded calls of each species was broadcast for a total of five minutes per species (30 second alternate intervals of broadcasting and listening), or until the species was detected, whichever occurred first. Each call playback session began and ended with a two minute listening and spotlighting period.

Spotlighting was conducted along the internal formal vehicle access tracks (Figure 2). A total of 60 km (including return trips) was surveyed using this technique, with surveys comprising four separate spotlighting routes, surveyed for up to four hours each, and each on a separate night (Table 1). Two of the routes (D2-D1, and D2-D6) were conducted entirely from a vehicle travelling at approximately 10 kph, one route (D2-D3) was conducted entirely by foot (total 1.3 km), and one route involved spotlighting 18.7 km by vehicle (D2-Site 3) followed by 5 km by foot (along the western boundary) (Figure 2).

Analyses

The relative success of each survey technique was investigated by comparing the total number of species detected, as well as the total number of "unique" species (i.e. those species not detected by any other technique) detected, by each technique. The usefulness of applying multiple techniques, over multiple days, and at multiple sites was examined using reptile species' detections at standardised survey sites as an example. Reptiles were selected for this analysis example as they provided the highest amount of capture data within the standardised survey sites.

Results

A total of 120 vertebrate species were identified during the combined pre-survey trips and the detailed fauna survey period (Table 2). The majority of these were native species ($n = 110$) representing each of the four main terrestrial vertebrate groups: 71 birds, 19 reptiles, 13 mammals, and seven amphibians. The remaining 10 species detected were all exotic mammals (Table 2).

Native species

The number of native species identified during this single survey is similar to the combined number of all prior species records for the reserve area ($n = 108$), yet the species composition varies considerably. Thirty-nine native species were detected that had not been previously recorded for the reserve area, and 35 species were not detected during this survey, despite being listed in prior records for the area. This single survey therefore detected higher species richness than the combined historical recorded species richness, and brought the total number of native species recorded for the reserve area to 146 (Table 2). Compared to prior species records, amphibians were the group with the highest proportional increase, with five new species being detected giving an increase in amphibian records of approximately 166%; amphibians were also the only group for which all species that had previously been recorded for the area were also detected during this survey (Table 2). The nine new reptile species detected increased the recorded reptiles for the area by almost 82%, and only one reptile species (Peron's Snake-eyed Skink, *Cryptoblepharus plagiocephalus*) was not detected during this survey, despite being recorded occurring within the reserve area 10 years prior (Table 2). Five new mammal species (mostly micro-bats) were detected, an increase of almost 24% from existing records; eight species were not detected (mostly small ground-dwelling mammals and micro-bats), despite being recorded within the area during the past 32 years (Table 2). For birds, 20 new native bird species were detected (an increase in existing records of approximately 25%), though 27 species listed in the existing records were not, including two threatened species (Table 2).

Significant native species

Seven of the species detected (three birds and four mammals) are listed as threatened under the NSW *Threatened Species Act 1995* (TSC Act) (Table 2). Three of the four mammal species were micro-bats and were new records for the reserve (Yellow-bellied Sheath-tail Bat, *Saccolaimus flaviventris*; Bristle-nosed Free-tail Bat, *Mormopterus eleryi*; and Little Pied Bat, *Chalinolobus picatus*). It should be noted that the *M. eleryi* records were not "definite" species identifications, but were considered "probable" species identifications. Two threatened bird species (Speckled Warbler, *Pyrrholaemus saggitatus*, and Superb Parrot, *Polytelis swainsonii*) that had previously been recorded within the area were not detected during this survey (Table 2). No *L. ocellata* individuals or signs of recent activity were detected during the current survey; though a single very old, degraded and abandoned mound was detected. This species is also absent from the historic species records for the reserve area, though the presence of the old mound indicates that they did once occur within the reserve.

Table 2. Combined species list for the reserve based on species detected during this current survey as well as prior species records (existing prior to this survey). **TSC Act Status** shows the legal conservation status of each species according to the NSW TSC Act: P = protected (i.e. non-threatened native species); V = vulnerable native species; E1 = endangered native species; X = exotic species; KTP = exotic species identified as a key threatening process. Threatened species are shown in bold. **Record Prior** indicates species records for the reserve area prior to this survey, according to the NSW Wildlife Atlas database; the year indicates the most recent record of the species, and a dash (-) indicates the species was not recorded prior to this current survey. **Record Current** indicates species identified during the current survey (✓) and those species not detected during the current survey (-). **Survey Technique** indicates the technique for which each species identified during this survey was detected (•): CT = cage trap, ET = Elliott trap, PF = pit-fall trap, HF = hair funnel; T/T = track or trace, An. = AnaBat™, BC = timed bird census, CP = call playback, Sp. = spotlighting (foot and car combined), AS = active search, IO = incidental observation. A hash (#) next to a micro-bat species' name indicates that identification to the species level was, at best, "probable" (not "definite").

Family	Scientific name	Common name	Tsc act status	Record		Survey technique										
				Prior	Current	CT	ET	PF	HF	T/T	An.	BC	CP	Sp.	AS	IO
AMPHIBIANS																
Hylidae	*Litoria caerulea*	Green tree frog	P	-	✓										•	
Hylidae	*Litoria peronii*	Peron's tree frog	P	-	✓										•	
Hylidae	*Litoria rubella*	Desert tree frog	P	-	✓										•	
Myobatrachidae	*Limnodynastes fletcheri*	Long-thumbed frog	P	-	✓										•	
Myobatrachidae	*Limnodynastes interioris*	Giant banjo frog	P	2000	✓										•	
Myobatrachidae	*Limnodynastes tasmaniensis*	Spotted grass frog	P	2000	✓										•	
Myobatrachidae	*Uperoleia rugosa*	Wrinkled toadlet	P	-	✓										•	
BIRDS																
Acanthizidae	*Acanthiza apicalis*	Inland thornbill	P	1998	✓							•				
Acanthizidae	*Acanthiza chrysorrhoa*	Yellow-rumped thornbill	P	1998	-											
Acanthizidae	*Acanthiza nana*	Yellow thornbill	P	1998	✓							•				•
Acanthizidae	*Acanthiza reguloides*	Buff-rumped thornbill	P	1998	-											
Acanthizidae	*Acanthiza uropygialis*	Chestnut-rumped thornbill	P	1998	✓											•
Acanthizidae	*Aphelocephala leucopsis*	Southern whiteface	P	1998	-											
Acanthizidae	*Gerygone fusca*	Western gerygone	P	1998	✓							•				•
Acanthizidae	*Pyrrholaemus saggitatus*	Speckled warbler		1977	-											
Acanthizidae	*Smicrornis brevirostris*	Weebill	P	-	✓							•				
Accipitridae	*Accipiter cirrocephalus*	Collared sparrowhawk	P	-	✓							•				
Accipitridae	*Accipiter fasciatus*	Brown goshawk	P	1977	-											
Accipitridae	*Aquila audax*	Wedge-tailed eagle	P	1978	-											
Accipitridae	*Elanus axillaris*	Black-shouldered kite	P	1977	-											
Accipitridae	*Hieraaetus morphnoides*	Little eagle	P	1977	-											
Aegothelidae	*Aegotheles cristatus*	Australian owlet-nightjar	P	1998	✓									•		•
Alcenidiae	*Dacelo novaeguineae*	Laughing kookaburra	P	1998	✓							•				•
Alcedinidae	*Todiramphus pyrrhopygia*	Red-backed kingfisher	P	1977	-											
Apodidae	*Hirundapus caudacutus*	White-throated needletail	P	1978	-											
Artamidae	*Artamus personatus*	Masked woodswallow	P	-	✓							•				

Family	Scientific name	Common name	Tsc act status	Record		Survey technique										
				Prior	Current	CT	ET	PF	HF	T/T	An.	BC	CP	Sp.	AS	IO
Artamidae	*Artamus superciliosus*	White-browed woodswallow	P	1998	✓							•				
Artamidae	*Cracticus nigrogularis*	Pied butcherbird	P	1998	✓							•				•
Artamidae	*Cracticus torquatus*	Grey butcherbird	P	1998	✓							•				•
Artamidae	*Gymnorhina tibicen*	Australian magpie	P	1998	✓							•				•
Cacatuidae	*Eolophus roseicapillus*	Galah	P	1998	✓							•				•
Cacatuidae	*Lophochroa leadbeateri*	Major Mitchell's cockatoo	V	1998	✓							•				•
Cacatuidae	*Nymphicus hollandicus*	Cockatiel	P	1998	✓							•				•
Campephagidae	*Coracina navaehollandiae*	Black-faced cuckoo-shrike	P	1998	✓							•				
Campephagidae	*Lalage sueurii*	White-winged triller	P	1998	✓							•				
Caprimulgidae	*Eurostopodus argus*	Spotted nightjar	P	1998	✓											•
Casuariidae	*Dromaius navaehollandiae*	Emu	P	1998	✓					•						•
Charadriidae	*Vanellus miles*	Masked lapwing	P	1977	-											
Charadriidae	*Vanellus tricolor*	Banded lapwing	P	-	✓											•
Columbidae	*Geopelia cuneata*	Diamond dove	P	-	✓							•				
Columbidae	*Geopelia humeralis*	Bar-shouldered dove	P	1998	✓							•				•
Columbidae	*Geopelia striata*	Peaceful dove	P	1998	✓							•				•
Columbidae	*Ocyphaps lophotes*	Crested pigeon	P	1998	✓							•				•
Columbidae	*Phaps chalcoptera*	Common bronzewing	P	1998	✓							•				•
Corcoracidae	*Corcorax melanorhamphos*	White-winged chough	P	-	✓					•		•				•
Coraciidae	*Eurystomus orientalis*	Dollarbird	P	1977	-											
Corcoracidae	*Struthidea cinerea*	Apostlebird	P	1998	✓							•				•
Corvidae	*Corvus coronoides*	Australian raven	P	1998	✓					•		•				•
Corvidae	*Corvus mellori*	Little raven	P	-	✓							•				•
Cuculidae	*Chalcites basalis*	Horsfield's bronze cuckoo	P	-	✓							•				
Cuculidae	*Chalcites osculans*	Black-eared cuckoo	P	1977	-											
Cuculidae	*Cuculus pallidus*	Pallid cuckoo	P	1977	-											
Dicaeidae	*Dicaeum hirundinaceum*	Mistletoebird	P	1998	✓							•				
Dicruridae	*Grallina cyanoleuca*	Magpie-lark	P	1998	✓							•				•
Dicruridae	*Myiagra inquieta*	Restless flycatcher	P	1998	✓							•				
Dicruridae	*Rhipidura fuliginosa*	Grey fantail	P	1998	✓							•				•
Dicruridae	*Rhipidura leucophrys*	Willie wagtail	P	1998	✓							•				•
Estrildidae	*Taeniopygia bichenovii*	Double-barred Finch	P	1978	-											
Falconidae	*Falco berigora*	Brown falcon	P	-	✓											•
Falconidae	*Falco cenchroides*	Nankeen kestrel	P	1978	-											
Hirundinidae	*Hirundo neoxena*	Welcome swallow	P	-	✓							•				•

Family	Scientific name	Common name	Tsc act status	Record		Survey technique										
				Prior	Current	CT	ET	PF	HF	T/T	An.	BC	CP	Sp.	AS	IO
Hirundinidae	*Petrochelidon ariel*	Fairy Martin	P	1977	-											
Hirundinidae	*Petrochelidon nigricans*	Tree martin	P	-	✓							•				
Maluridae	*Malurus lamberti*	Variegated fairy-wren	P	1998	-											
Maluridae	*Malurus splendens*	Splendid fairy-wren	P	1998	✓							•				•
Meliphagidae	*Acanthagenys rufogularis*	Spiny-cheeked honeyeater	P	1998	✓							•				•
Meliphagidae	*Certhionyx niger*	Black Honeyeater	P	1998	-											
Meliphagidae	*Entomyzon cyanotis*	Blue-faced honeyeater	P	1998	✓							•				•
Meliphagidae	*Epthianura tricolor*	Crimson chat	P	-	✓							•				•
Meliphagidae	*Lichenostomus ornatus*	Yellow-plumed honeyeater	P	1998	✓											•
Meliphagidae	*Lichenostomus penicillatus*	White-plumed honeyeater	P	-	✓							•				
Meliphagidae	*Lichenostomus plumulus*	Grey-fronted honeyeater	P	-	✓							•				•
Meliphagidae	*Manorina flavigula*	Yellow-throated miner	P	1977	-											
Meliphagidae	*Manorina melanocephala*	Noisy miner	P	1998	✓							•				•
Meliphagidae	*Melithreptus brevirostris*	Brown-headed honeyeater	P	1998	✓							•				•
Meliphagidae	*Philemon citreogularis*	Little Friarbird	P	1998	-											
Meliphagidae	*Philemon corniculatus*	Noisy friarbird	P	1998	✓							•				•
Meliphagidae	*Phylidonyris albifrons*	White-fronted honeyeater	P	1998	-											
Meliphagidae	*Plectorhyncha lanceolata*	Striped honeyeater	P	1998	✓							•				•
Meropidae	*Merops ornatus*	Rainbow bee-eater	P	1998	✓							•				•
Neosittidae	*Daphoenositta chrysoptera*	Varied sittella	P	-	✓							•				
Pachycephalidae	*Colluricincla harmonica*	Grey shrike -thrush	P	1998	✓							•				•
Pachycephalidae	*Oreoica gutturalis*	Crested bellbird	P	1998	✓							•				
Pachycephalidae	*Pachycephala inornata*	Gilbert's whistler	V	1998	✓							•				
Pachycephalidae	*Pachycephala pectoralis*	Golden whistler	P	1977	-											
Pachycephalidae	*Pachycephala rufiventris*	Rufous whistler	P	1998	✓							•				•
Pardalotidae	*Pardalotus punctatus*	Spotted pardalote	P	-	✓							•				
Pardalotidae	*Pardalotus striatus*	Striated pardalote	P	1998	✓							•				
Petroicidae	*Eopsaltria australis*	Eastern yellow robin	P	1998	✓							•				•
Petroicidae	*Microeca fascinans*	Jacky winter	P	1998	✓							•				•
Petroicidae	*Petroica goodenovii*	Red-capped robin	P	1998	✓							•				
Phasianidae	*Coturnix sp.*	Unidentified Quail	?	1998	-											
Podicipedidae	*Tachybaptus novaehollandiae*	Australasian grebe	P	-	✓							•				•
Podargidae	*Podargus strigoides*	Tawny frogmouth	P	1998	-											
Pomatostomidae	*Pomatostomus superciliosus*	White-browed babbler	P	1998	✓							•				

Family	Scientific name	Common name	Tsc act status	Record		Survey technique										
				Prior	Current	CT	ET	PF	HF	T/T	An.	BC	CP	Sp.	AS	IO
Pomatostomidae	*Pomatostomus temporalis temporalis*	Grey-crowned babbler (eastern subsp.)	V	1998	✓							•				•
Psittacidae	*Barnardius zonarius barnardi*	Australian 'mallee' ringneck	P	1998	✓							•				•
Psittacidae	*Melopsittacus undulatus*	Budgerigar	P	-	✓							•				•
Psittacidae	*Northiella haematogaster*	Blue bonnet	P	1998	✓							•				•
Psittacidae	*Platycercus adscitus eximius*	Eastern rosella		1998	-											
Psittacidae	*Polytelis swainsonii*	Superb parrot	V	2008	-											
Psittacidae	*Psephotus haematonotus*	Red-rumped parrot	P	1977	✓							•				•
Psittacidae	*Psephotus varius*	Mulga parrot	P	1995	✓											•
Ptilonorhychidae	*Ptilonorhynchus maculatus*	Spotted bowerbird	P	-	✓							•				•
Sylviidae	*Cincloramphus mathewsi*	Rufous songlark	P	-	✓							•				
Sturnidae	*Sturnus vulgaris*	Common starling	X	1977	-											
MAMMALS																
Bovidae	*Bos taurus*	European cattle	X	-	✓					•						
Bovidae	*Capra hircus*	Goat	KTP	1995	✓					•						•
Bovidae	*Ovis aries*	Sheep (feral)	X	1998	✓					•						•
Canidae	*Canus familiaris*	Dog	KTP	-	✓					•						
Canidae	*Vulpes vulpes*	Red fox	KTP	1998	✓					•						•
Cervidae	*Cervus sp.*	Unidentified Deer	X	2006	-											
Dasyuridae	*Antechinomys laniger*	Kultarr	E1	1979	✓									•		
Emballonuridae	*Saccolaimus flaviventris*	Yellow-bellied sheath-tail bat	V	-	✓						•					
Felidae	*Felis catus*	Cat	KTP	-	✓					•						
Leporidae	*Lepus capensis*	Brown hare	X	-	✓					•						•
Leporidae	*Oryctolagus cuniculus*	European rabbit	KTP	-	✓					•						•
Dasyuridae	*Antechinus flavipes*	Yellow-footed antechinus	P	1979	-											
Dasyuridae	*Planigale tenuirostris*	Narrow-nosed planigale	P	1976	-											
Dasyuridae	*Sminthopsis crassicaudata*	Fat-tailed dunnart	P	1981	-											
Dasyuridae	*Sminthopsis murina*	Common dunnart	P	1979	-											
Macropodidae	*Macropus fuliginosus*	Western grey kangaroo	P	1994	✓									•		
Macropodidae	*Macropus giganteus*	Eastern grey kangaroo	P	1998	✓				•	•				•		
Macropodidae	*Wallabia bicolor*	Swamp wallaby	P	1998	-											
Molossidae	*Austronomis australis*	White-striped freetail bat	P	1994	-											
Molossidae	*Mormopterus sp.*	Mastiff-bat	P	1998	-											
Pteropodidae	*Pteropus scapulatus*	Little red flying-fox	P	1998	-											

Family	Scientific name	Common name	Tsc act status	Record		Survey technique										
				Prior	Current	CT	ET	PF	HF	T/T	An.	BC	CP	Sp.	AS	IO
Molossidae	*Mormopterus eleryi* #	Bristle-faced freetail bat	V	-	✓						•					
Molossidae	*Mormopterus "species 4"*	South-eastern freetail bat	P	-	✓						•					
Muridae	*Mus musculus*	House mouse	X	-	✓		•									
Suidae	*Sus scrofa*	Pig	KTP	-	✓					•						•
Tachyglossidae	*Tachyglossus aculeatus*	Short-beaked echidna	P	-	✓					•						
Vespertilionidae	*Chalinolobus gouldii*	Gould's wattled bat	P	1998	✓						•					
Vespertilionidae	*Chalinolobus picatus*	Little pied bat	V	-	✓						•					
Vespertilionidae	*Nyctophilus geoffroyi*	Lesser long-eared bat	P	1998	-											
Vespertilionidae	*Nyctophilus sp.*	Unidentified Long-eared bat	P	-	✓						•					
Vespertilionidae	*Scotorepens balstoni*	Inland broad-nosed bat	P	1998	✓						•					
Vespertilionidae	*Scotorepens greyii*	Little broad-nosed bat	P	1989	✓						•					
Vespertilionidae	*Vespadelus sp.*	Unidentified Eptesicus	P	1998	-											
Vespertilionidae	*Vespadelus vulturnus*	Little forest bat	P	1994	✓						•					
REPTILES																
Agamidae	*Amphibolurus nobbi coggeri*	Nobbi dragon	P	-	✓			•								
Agamidae	*Pogona barbata*	Bearded dragon	P	-	✓			•						•		
Elapidae	*Brachyurophis australis*	Coral snake	P	-	✓			•								
Elapidae	*Demansia psammophis*	Yellow-faced whip-snake	P	-	✓											•
Elapidae	*Vermicella annulata*	Bandy-bandy	P	-	✓									•		
Gekkonidae	*Diplodactylus vittatus*	Eastern stone gecko	P	1998	✓			•								
Gekkonidae	*Gehyra variegata*	Common dtella	P	1998	✓										•	
Gekkonidae	*Heteronotia binoei*	Bynoe's gecko	P	1998	✓										•	
Gekkonidae	*Rhynchoedura ornata*	Beaked gecko	P	-	✓			•							•	
Gekkonidae	*Strophurus intermedius*	Southern spiny-tailed gecko	P	1998	✓			•							•	
Pygopodidae	*Pygopus schraderi*	Eastern hooded scaly-foot	P	-	✓			•								
Scincidae	*Cryptoblepharus plagiocephalus*	Péron's snake-eyed skink	P	1998	-											
Scincidae	*Ctenotus allotropis*	Brown-blazed wedgesnout	P	-	✓			•								•
Scincidae	*Egernia striolata*	Tree skink	P	1998	✓		•	•								
Scincidae	*Lerista muelleri*	Three-toed lerista	P	1998	✓			•								
Scincidae	*Lerista punctatovittata*	Eastern robust slider	P	-	✓			•								
Scincidae	*Morethia boulengeri*	Boulenger's morethia	P	1998	✓			•								•
Scincidae	*Tiliqua rugosa*	Shingleback	P	1998	✓	•		•								•
Varanidae	*Varanus gouldii*	Sand monitor	P	1998	✓	•										•
Varanidae	*Varanus varius*	Lace monitor	P	1998	✓					•						•

Exotic species

Twice as many exotic species were detected during the current survey than had previously been recorded within the area, including seven species that had not previously been recorded (Table 2). Only two previously recorded species were not detected during the current survey (Common Starling, *Sturnis vulgaris*, and Unidentified Deer, *Cervus* sp.).

Significant exotic species

Five of the exotic vertebrate species identified during the survey period are listed as key threatening processes under the NSW TSC Act (Table 2). A key threatening process is one which "…*adversely affects threatened species, populations, or ecological communities, or…could cause species, populations or ecological communities that are not threatened to become threatened.*" (Part 2, Division 2, Section 13, New South Wales Government 2011b). It should be noted that given the proximity to neighbouring private residences, the Dog, *Canis familiaris*, and Cat, *Felis catus*, records for the reserve are not able to be definitively determined as feral or domestic, although both feral and domestic cats and dogs are likely to have similarly detrimental impacts on native fauna.

Survey design

Technique effectiveness

With the exception of call playback, all of the survey techniques identified at least one species, with nine of the techniques identifying at least one "unique" species - defined here as a species detected by only a single technique. The effectiveness of each technique for detecting species varied depending on the fauna group, with the same patterns of effectiveness being found for absolute (i.e. total number of species) and relative (i.e. number of species per survey effort) comparisons (Figure 4).

The seven amphibian species were detected using nocturnal active searches (including call recognition) targeted around the dams (Table 2, Figure 4). Three of the dams contained water during the survey period and the highest amphibian activity was observed around the two of these dams that also supported fringing aquatic vegetation. All seven amphibian species were unique species for the active search technique (Figure 4).

The 71 bird species were detected using a combination of timed bird census, incidental observation (including call recognition), spotlighting, and track/trace identification techniques (Table 2, Figure 4). Timed bird censuses detected both the highest number of bird species (n = 62 or 87 %) and the highest number of unique bird species (n = 20, or 28 %) (Figure 4). Incidental observations also detected a high diversity of species (n = 51, or 72 %), including seven unique species (Table 2). Spotlighting detected a single bird species (Australian Owlet-nightjar, *Aegotheles cristatus*), which was also detected by incidental call recognition. Although a large number of tracks/traces (observed on sand plots and elsewhere incidentally) indicated the presence of various bird species, none were able to

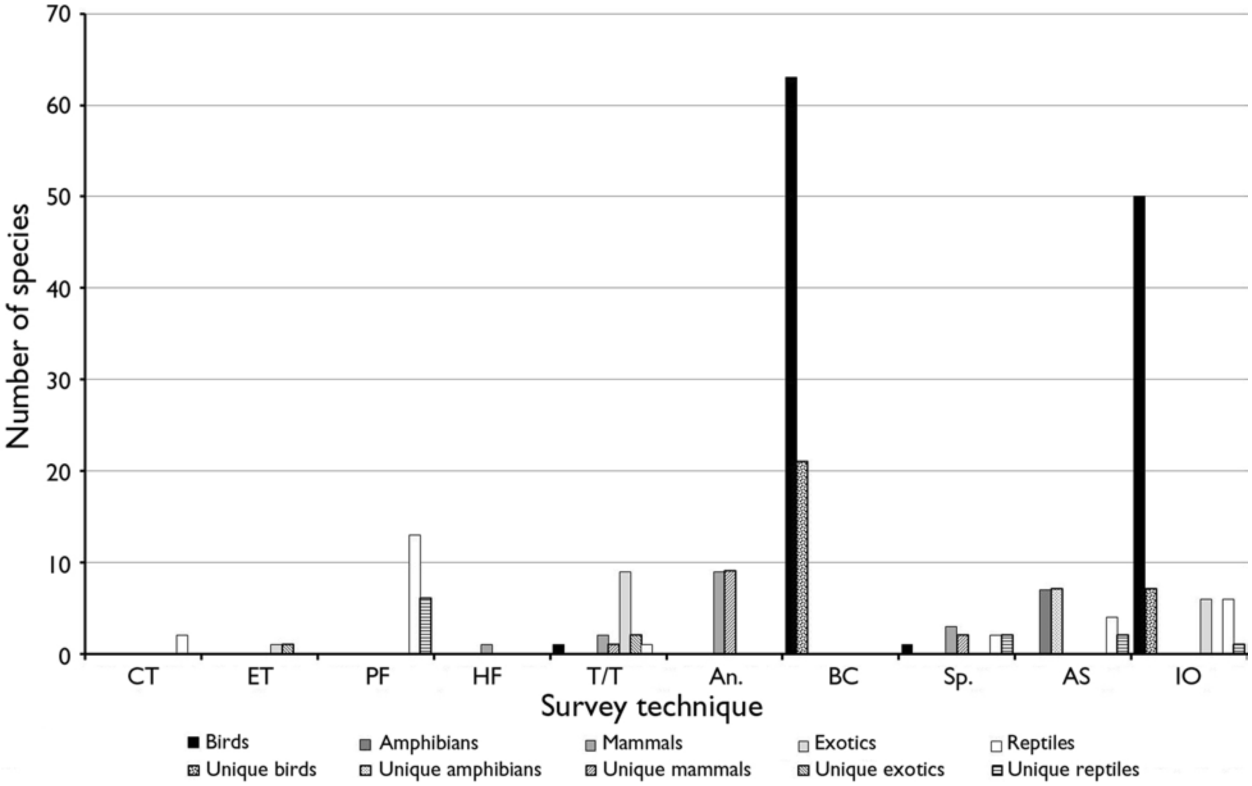

Figure 4. Relative success of each survey technique, showing the total number of species, and the total number of unique species (within each fauna group) detected by each survey technique: CT = cage trap, ET = Elliott trap, PF = pit-fall trap, HF = hair funnel; T/T = track or trace, An. = AnaBatTM, BC = timed bird census, Sp. = spotlighting (foot and car combined), AS = active search, IO = incidental observation. Call playback is not shown here as no species were detected using this technique.

be definitively identified to the species level, with the exception of Emu (*Dromaius navaehollandiae*) tracks and scats, tracks of the Australian Raven (*Corvus coronoides*), and the distinctive mud nests of White-winged Choughs (*Corcorax melanorhamphos*). No signs of recent *L. ocellata* activity were observed within the reserve, though the old, degraded *L. ocellata* mound was detected through incidental observation.

The 13 native mammal species were detected using a combination of spotlighting, track/trace identification, hair funnels, incidental observation, and AnaBat™ techniques (Table 2, Figure 4). Of these techniques, AnaBat™ recording detected the highest diversity of mammal species (*n* = 9, or 69 %), all of which were unique species for this technique. This technique therefore also detected the most unique species of all the techniques which detected mammals (*n* = 9, or 75 %) (Figure 4). This is unsurprising given the majority of native mammals detected were micro-bats and AnaBat™ is specifically designed to detect these species. It should be noted that although nine species have been included in the species list, only seven of these species were positively identified to the species level. Records of *M. eleryi* and Little Forest Bat, *Vespadelus vulturnus*, are included based on expert identification and opinion, though they were, at best, only probable identifications to the species level given the difficulty in distinguishing these species' calls from other species that may also be found in the area (further detail available in Garden *et al.* 2009). The single Kultarr, *Antechinomys laniger*, sighting occurred whilst spotlighting from slow moving vehicles. Spotlighting also identified two macropod species, with the Western Grey Kangaroo, *Macropus fuliginosus*, being identified only by spotlighting, whereas the Eastern Grey Kangaroo, *M. giganteus*, was also identified from a single hair funnel sample and from track/trace identification (specifically from scat identification, including as part of prey contents in predator scat). Incidental track/trace identification also detected the presence of the Short-beaked Echidna, *Tachyglossus aculeatus*, which was the only unique species for this technique.

The 10 exotic mammals were identified using a combination of track/trace identification, incidental observation, and Elliott trapping techniques (Table 2, Figure 4). Track/trace identification detected nine of the ten exotic species, of which three were unique species (Figure 4), with the other six species also being detected by incidental observations (Table 2). The House Mouse, *Mus musculus*, was identified only from Elliott trap captures of two individuals, and was the only mammal species (native or exotic) to be detected by this technique (Table 2).

The 19 reptile species were identified using a combination of pit-fall trapping, cage trapping, Elliott trapping, active searches, spotlighting, incidental observation, and track/trace identification techniques (Table 2). Of these techniques, pit-fall trapping identified the highest diversity of reptile species (*n* = 13, or 68 %), including six of the 10 unique reptile species detected (Figure 4). Active searches identified four species (including two unique species), incidental observations identified six species (including one unique species), spotlighting identified two species (including one unique species), cage trapping identified two species (none unique), and Elliott trapping and track/trace identification each identified a single species (neither unique) (Table 2, Figure 4). In general, trapping survey techniques (particularly pit-fall trapping) were best for identifying diurnal, small-medium bodied species (e.g. skinks, small snakes), whereas non-trapping techniques such as spotlighting and active searches were best for identifying geckos and other small and/or nocturnal species (e.g. Bandy-bandy, *Vermicella annulata*). Incidental observations and track/trace identification techniques were best for identifying large-bodied diurnal species (e.g. Lace Monitor, *Varanus varius*).

Species accumulation curves

The number of reptiles detected within each standardised survey site increased from 1-3 species on the first day of survey to 3-7 species by the final survey day (Figure 5a). The largest increase in species richness was at site A (Figure 2) where two species were detected on the first day of surveying, and an additional five species had been detected by the end of the survey period (Figure 5a). The numbers of species detected at each survey site was much lower than the combined total species detected across all sites, with 8 to 15 species detected at all standardised survey sites across the survey period. This indicates that species diversity detected at each site was generally quite different. Similar trends were apparent when species accumulation curves were plotted for reptiles detected only by pit-fall trapping at each standardised survey site, though the total number of species detected was consistently one to two species fewer, indicating that the number of reptile species detected would have been lower had only pit-fall trapping (the most successful reptile survey technique) been employed (Figure 5b).

Species accumulation curves (pooling all data from all survey techniques) were also recorded for all native species (and major species groups) detected during all visits to the reserve, including the two reconnaissance days and the two pre-survey preparation days. Nineteen native species were detected incidentally during the first reconnaissance visit, with an increasing number of native species detected on each subsequent day spent within the reserve. The rate of species' detections also increased following the commencement of the detailed survey period, when additional non-trapping and trapping techniques began to be utilised. On the final day of the survey period, the overall species accumulation curve appeared to be approaching an asymptote, indicating that a large proportion, though not all, of the species occurring within the reserve had been detected. These curves are not shown here, but may be found in Garden *et al.* 2009.

Figure 5a.

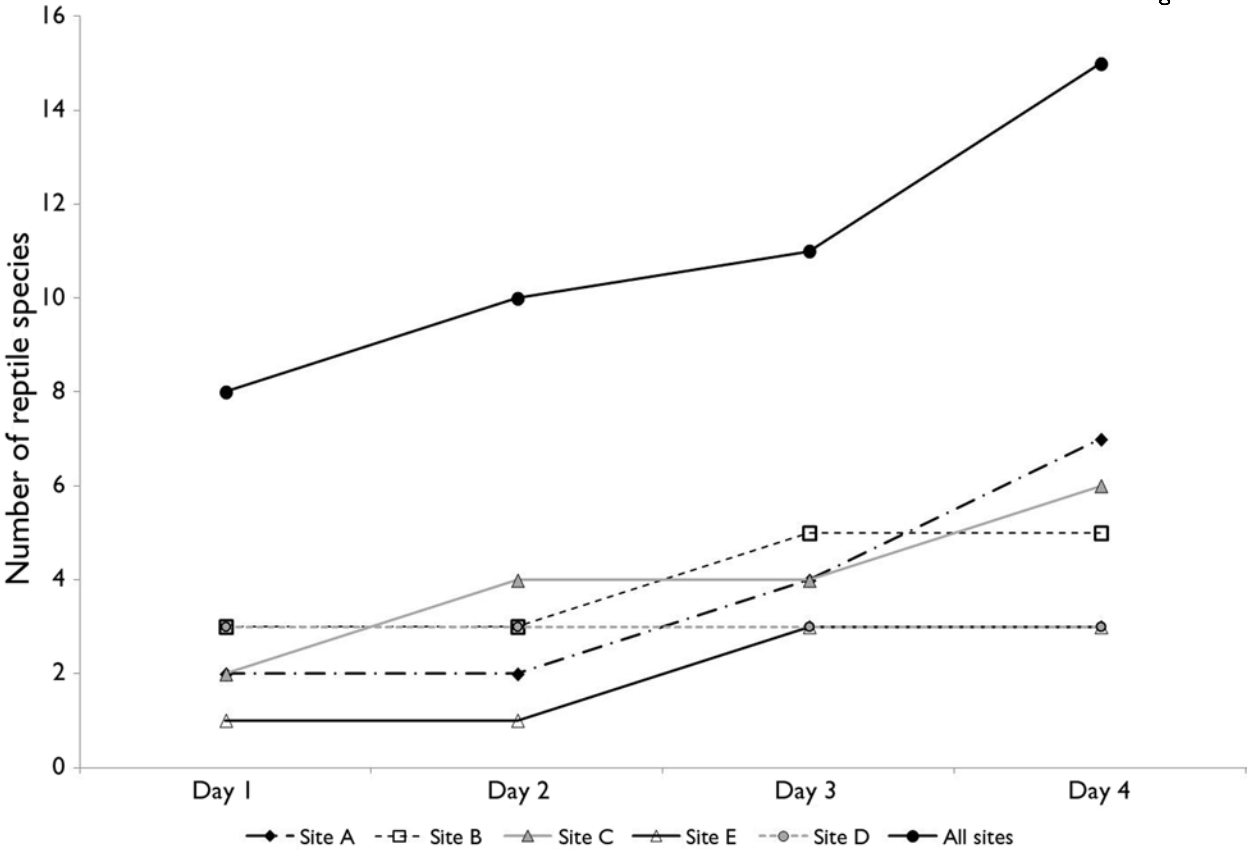

Figure 5b.

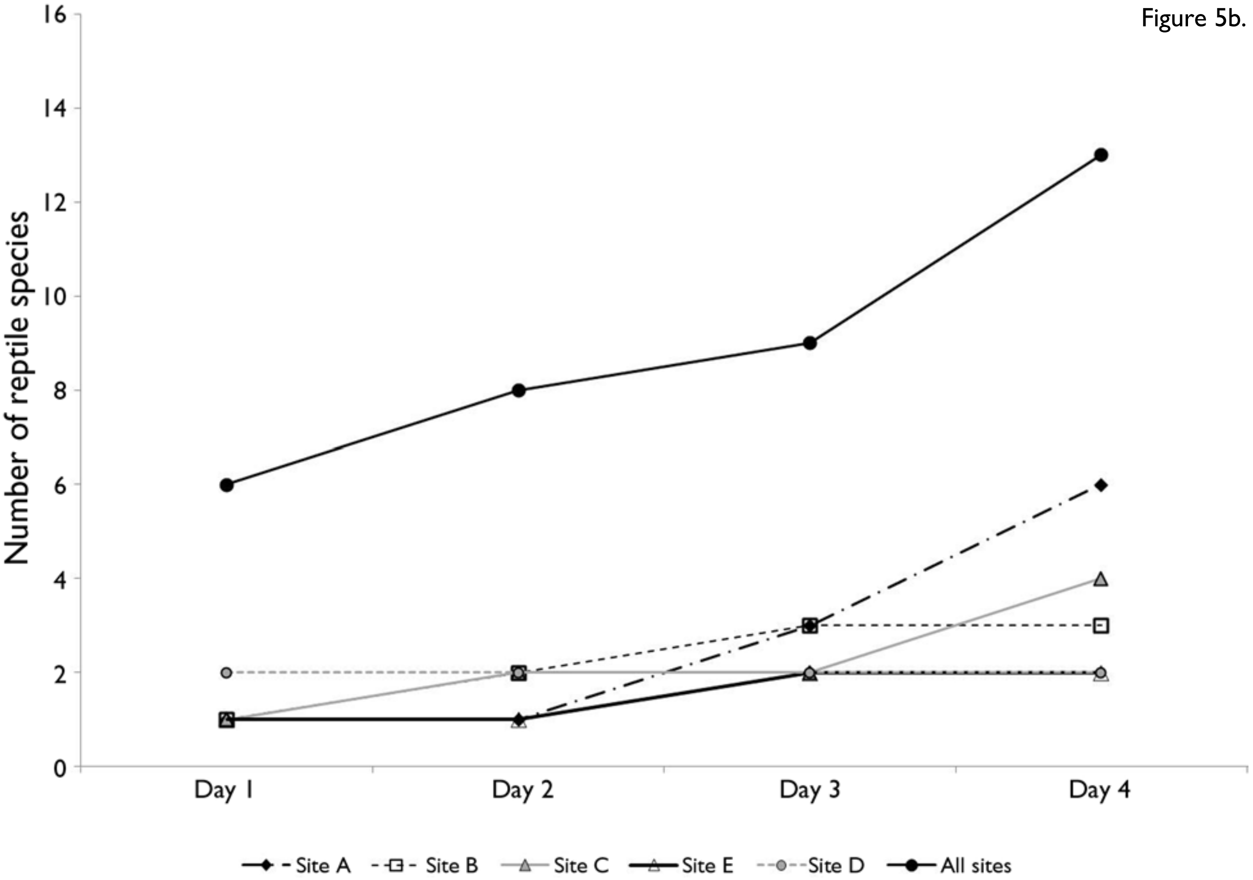

Figure 5. Species accumulation curves showing (a) reptiles detected within standardised survey sites using a combination of techniques, and (b) reptiles detected within standardised survey sites using only pit-fall trapping.

Discussion

Species detected and conservation implications

The vertebrate fauna survey of Quanda NR detected 110 native and ten exotic species, of which 35 % and 70 % (respectively) had not previously been recorded within the area. This large number of previously unrecorded species is not unexpected given that this was the first detailed fauna survey focussed specifically within the reserve since it was gazetted 1963. Although a large proportion of the species likely to occur within the reserve are considered to have been detected during this survey, the species list is still considered to be incomplete. This is particularly so given this survey's primary focus on one vegetation community coupled with other limitations and biases commonly associated with ecological field surveys (e.g. survey duration, available resources, time of year, lack of repetition). The findings nonetheless highlight the importance of conducting focussed and detailed fauna surveys of protected areas, including surveying replicate sites over multiple days, rather than simply relying on historical data and rapid assessment techniques; as the resulting knowledge of species occurrences is likely to have substantial implications for the selection, and ultimate success, of conservation management strategies.

As well as knowledge regarding species occurrences within protected areas, understanding species absences will also be important. Such balanced knowledge will be of substantial importance for underpinning conservation strategies and management plans, particularly when species which may potentially occur within an area require opposing management strategies (e.g. regular versus long-unburnt fire regimes). Definitively determining a species' absence however is more complicated, given the propensity for false-absences during field surveys. For example, of particular note for Quanda NR is the apparent absence of *L. ocellata*. The reserve was initially protected in order to conserve this species' suitable habitat, yet there are no historical records in the available databases of this species occurring within the reserve, and no recent tracks or traces were detected during the survey. This lack of historical records and recent signs of activity are indicative that the species may not occur within the reserve, despite suitable habitat remaining. However, the detection of an old *L. ocellata* mound indicates that the species has actually previously occurred within the reserve, and so the lack of historical records of this species is likely due to false-absences, rather than true absences. Such issues of proving false-absences are particularly pertinent to cryptic and rare species, which are often also the species that have specific disturbance sensitivities and habitat requirements and for which management actions are targeted. Accordingly, definitively determining known presences or absences will be particularly important in underpinning management actions and strategies.

Effectiveness of survey techniques

The highest diversity of species (including unique species) was detected using a combination of: bird census, pit-fall trapping, AnaBat^{TM} recording, incidental observation, and active search (combined with spotlighting) techniques. The relative success of each technique varied depending on the fauna group, which is consistent with the findings from previous studies (e.g. Mengak and Guynn 1987; Laurence 1992; Catling *et al.* 1997; Crosswhite *et al.* 1999; Doan 2003; Garden *et al.* 2007). It is important to note, though, that the techniques found to be most successful in one study for a certain species group, may not necessarily be the same as that in another study. For example, pit-fall traps were found to be more successful than Elliott traps for detecting small terrestrial mammals in the arid environments of Little Desert National Park, Victoria (Clemann *et al.* 2005), yet Elliott traps rather than pit-fall traps were found to be more successful in the dry sclerophyll forests of South East Queensland (Garden *et al.* 2007). Such discrepancies in relative trap effectiveness may also arise for other reasons, such as: different habitat types, species-specific responses/sensitivities to traps, the bait being used, the physical attributes of traps (e.g. size and shape, modifications such as drift-fences and covers for pit-fall traps), and even the residual smell on traps from previous captures (Friend *et al.* 1989; Hobbs and James 1999; Lindenmayer *et al.* 1999; Mills *et al.* 2002; Ryan *et al.* 2002; Thompson *et al.* 2005). There are therefore a number of elements, in addition to the survey objectives and target fauna species/groups, which must be considered when selecting survey techniques, and reporting on the relative success of different techniques for various species and habitats is strongly advocated as an important step following any survey (e.g. Tasker and Dickman 2002; Garden *et al.* 2007).

Nonetheless, when the objective of a survey is to detect as many species and species groups as possible, the combined use of multiple survey techniques over an extended period of time is advocated to maximise species detection success. This may prove difficult, as many surveys are resource and time limited and as such, short diurnal surveys using only incidental and/or rapid assessment techniques (e.g. bird census, spotlighting) are commonly used in lieu of more time consuming and costly trapping techniques and longer survey periods. This survey, however, demonstrates that short-term surveys and/or the use of only rapid assessment techniques is likely to substantially under-represent the species diversity of an area. For example, less than one-third of the overall species would have been detected had only the first day of this survey occurred. Furthermore, had only diurnal incidental/rapid survey techniques been employed in the current survey (over the total survey duration), the overall species diversity recorded would have been significantly lower; particularly for reptiles and amphibians, whose diversity would have been under-represented by 52 % and 100 %, respectively. From a conservation management perspective, this highlights the importance of conducting detailed fauna surveys over a number of days using a variety of survey techniques, rather than simply relying on short-term surveys using only rapid assessment techniques. Management and conservation decisions based on such rapid survey findings may be misguided and potentially ineffective in achieving conservation goals.

Survey limitations and future recommendations

Despite detecting a high diversity of species, representing each of the four major vertebrate groups, the species recorded during this survey are considered an incomplete list of the species that may occur on the reserve. This is supported by the several new species that had not been detected previously, as well as the number of species recorded in prior surveys that were not detected during this survey (i.e. potential false-absences). The four night duration of this survey is the standard recommended minimum duration for terrestrial vertebrate surveys, and may be suitable for detecting the majority of certain species (e.g. Parris *et al.* 1999), though extended survey periods may be necessary to detect the full complement of certain species and groups within an area. For example, detecting the full complement of mammals in an area may require longer survey periods than for reptiles (Moseby and Read 2001). Longer survey periods are particularly important for detecting rare and/cryptic species which tend to occur at lower densities (and so may not be encountered as often) and may require a longer "habituation" period towards survey techniques; although being able to survey multiple sites simultaneously may help to counter the effect of shorter survey periods (e.g. Moseby and Read 2001).

In addition, conducting only a single survey within any given year is likely to overlook species which may occur in an area seasonally (e.g. migrants) or as infrequent visitors. As such, the most adequate length of time for detecting the full complement of species within an area is likely to vary, and decisions need to be made regarding the trade-offs among survey duration, number of sites, survey repetition, and detection success (MacKenzie and Royal 2005). Such decisions will depend largely on the underlying objectives of the survey, as well as specific resource and time constraints. However, where no baseline data exists and the objective is to detect as many species as possible within an area (including rare/cryptic species), it is suggested that surveys adopt a flexible duration, with the standard four nights as a minimum but continuing for up to 10 nights, when possible (Moseby and Read 2001), or until no new species have been detected for three consecutive nights, whichever occurs first. Repeated surveys in at least one other "opposite" season (i.e. spring or summer versus autumn or winter) are also likely to help to detect seasonal and transient species which may otherwise be missed.

In addition to the limited duration and "temporal snap-shot" nature of this survey, other limitations which may have influenced the species' detection success include: the focus on a single vegetation community; the focus on terrestrial species; and, the lack of certain survey techniques. The primary focus for this survey was the reserve's old growth mallee vegetation community, meaning that species which may occur only/predominantly within other habitat types in the reserve may have been overlooked. In addition, the focus on terrestrial vertebrate species means there remains a paucity of information regarding invertebrate and aquatic species diversity. Having a comprehensive understanding of species diversity and their habitat associations within the reserve will be critical for informing effective conservation management decisions. What's more, invertebrate surveys (in addition to vertebrate surveys) can be useful in providing insights into community dynamics as well as the environmental health of the area (Bisevac and Majer 2002). The use of additional specialist survey techniques, such as harp trapping for micro-bats and funnel traps for snakes, may also have detected additional species.

Conclusion

The detection of a wide range of vertebrate species (though not considered entirely comprehensive) provides an important foundation on which to develop appropriate conservation management objectives and strategies. It also provides a benchmark for assessing the success of such actions in the short- and long-term. Further detailed surveys covering habitats and fauna groups not able to be surveyed at this time, using additional survey techniques, and occurring at different times during the year, would supplement the species list from this survey and help to clarify the species' composition within the reserve. Above all else, this survey highlighted the importance of conducting detailed fauna surveys within protected areas, without which, management objectives and actions may be unsuccessful and/or inefficient, and may even prove counter-productive. It is important that such detailed fauna surveys be prioritised, and be conducted in a scientifically rigorous and repeatable manner. Doing so enables future monitoring surveys to be consistent and directly comparable, and so provide sound, scientifically rigorous data which may be used to evaluate the effectiveness of management actions, and also provide defensible support for potential changes that may be required to management plans and regimes.

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